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## Methodological approaches for use virtual reality to develop emergency evacuation simulations for training, in emergency situations

Sarah Moreira Fernandes Bernardes<sup>a,b,c,\*</sup>, Francisco Rebelo<sup>a,b</sup>, Elisângela Vilar<sup>a,b</sup>,  
Paulo Noriega<sup>a,b</sup>, Tania Borges<sup>a,d</sup>

<sup>a</sup>Ergonomics Laboratory – FMH - Lisbon University, Estrada da Costa – Cruz Quebrada, 1499-002, Portugal

<sup>b</sup>CIAUD - Research Centre for Architecture, Urban Planning and Design, Rua Sá Nogueira, Alto da Ajuda, 1349-055 Lisboa, Portugal

<sup>c</sup>CAPES Foundation, Ministry of Education of Brazil, Brasília - DF 70040-020, Brazil

<sup>d</sup>ISCTE - Institute of Lisbon, Avenida das Forças Armadas, 1649-026 Lisbon, Portugal

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### Abstract

Several research studies have shown that training using simulations is a good strategy to promote the performance of students and work teams [1]. The effectiveness of the training, in terms of transfer, using simulations, has been proved for pilots (flight simulators) and surgeons (virtual reality systems) [2]. These simulations, based in expensive technology solutions, are very difficult to be implemented in companies, for training workers for emergency fire evacuation. In everyday situations, particularly in the emergency associated with rapid evacuation of people in buildings, is required by law, the development of fire drills. The main objective of these methods is to train the workers to peacefully follow a previously taught routine. However, in a real emergency, workers can be under a high stress situation and may not follow the previously trained behavior. This article will reflect on emergency evacuation in buildings and how the effectiveness of the training process can be increased. Thus, a theoretical approach of emergency evacuation will be presented and a discussion of VR as the usage for training in these situations.

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\* Corresponding author. Tel.: +351 925 319 732.

E-mail address: [sarah.mfber@gmail.com](mailto:sarah.mfber@gmail.com)

## 1. Introduction

The number of occupants in large cities is growing drastically, increasing the need for the construction of buildings that became more vertical. These can vary from housings, companies, and renowned multinationals to small commercial buildings. Due to this growing population density, it is of vital importance to investigate the human-environment interaction with the objective of securing the human condition using such environments.

In this context, Laws were determined to model these periodical events of exercises, where the individuals learn and train how to behave in an emergency evacuation situation. Among these exercises we point out the exercise of evacuation also referred as simulacrum. These exercises focus in the users' familiarization with the buildings, expecting that when they are exposed to the real situation of fire the users will know how to behave in these situations finding a safety place or the emergency exits as soon as possible. Usually, the simulacrum exercise is previously oriented and starts after the fire alarm, this alarm implies that something is not right. So, in some situations, when people are in a real situation of fire, they may infer that the alarm is nothing more than an exercise of evacuation [3]. The reaction before this situation is closely linked to the skepticism of the individuals concerning the emergency alarm, because these procedures are focused in the structural aspects of buildings rather than in the individual responses of the subjects behaviour [4, 6].

Currently a widely used tool for training people in various professions (e.g., airline pilots, doctors and engineers) and has been very successful in the transfer of knowledge is Virtual Reality (VR). The VR gives the user the feeling of being present in the situation, in a wide variety of settings and circumstances and can be used in a laboratory environment or even in a game format[7].

It can be inferred that the simulacrum is not generating the expected response previously trained because they lack more interaction in the initial phase of evacuation. In this sense, VR can be used to solve this problem, through scenarios that refer to both routine situations as critical situations (obstruction of fire escapes) and an analysis of the behaviour of individuals, particularly in the initial phase of evacuation.

In this context, this article aims to present a reflection on emergency evacuation in buildings to increase the effectiveness of the training process. A theoretical approach to emergency evacuation will be presented as well as a discussion of VR usage for training in these situations.

## 2. Background

In this section the emergency evacuation aspects and evacuation models will be addressed. Furthermore, attitudes and behaviours of individuals facing this situation, the use of VR as a training tool and the transfer of knowledge attained using the VR-training approach for emergency situation will also be investigated.

### 2.1. The emergency evacuation

The fire is the response of the interaction of a burning material (either synthetic or vegetation) and the rapid oxidation producing heat and smoke. Under fire conditions, most of the deaths are associated with inhalation of smoke, toxic gases and burns. Facing a fire situation the act of moving from the place of danger to find shelter is called evacuation.

Emergency evacuation is the process of orientation and navigation in critical situations (e.g., fires, landslides, floods). In this case, occupants must escape quickly from the danger and find a safe place. This process involves many aspects of the behaviour and responses to be taken, pointing out those that interfere negatively in this attitude [6, 8]:

- The difficulty to visual access of emergency exits may be associated with smoke, obstructed emergency door or falls.
- Audible alarm.
- Building or room layout (building with exits and entrances, resembling a maze).
- Little familiarity with the structure.
- Individual behaviour (panic, stress).

- Decreased risk perception (may be associated with the state or even the lack of concern with alarm).

It is known, however, that the faster the response reaction of the individual's in a fire and smoke situation, the greater their chance of survival[9]. This response is associated with some clues such as hearing the fire alarm, smelling the smoke and the abnormal behaviour of other occupants

So when faced with the imminent danger, the individual performs three actions inherent to its own conceptions, which are the perception of the circumstances that surround the individuals, the analysis of which attitudes to take and what the full evacuation process is, in order to survive[10].

The emergency evacuation study had its rise from the middle of the 20th century. In the beginning the aim was to analyze the structural and organizational aspects of the establishments, providing some improvements such as, changing the minimum width of the stairs and the number of emergency exits. However, with further studies and major incidents in this area, it became necessary to also analyze the behaviour and responses of individuals dealing with emergency situations[11] .

Emergency evacuation, can be divided into phases that can be defined as pre movement, movement and the complete evacuation phase[9, 11, 12]:

- I. The pre movement phase is divided into two phases, the validation of clues or signs and decision making. The validation of clues or signs is one of the main processes of this phase, it is at this point that the individual analyzes and interprets the surroundings, leading to understand what condition he/she is being exposed to. Examples of clues that indicate hazards are: smoke, fire, fire alarm, voice command and noises in the structures. This phase is also the phase where the individuals are exposed the behaviour and risk perception, that is, if it comes or not to a state of shock, or if the panic hinders or delays the evacuation phase. This is an important phase to be studied due to the fact that many people fail in acting properly and miss the clues validation, making decisions that can delay the evacuation process. Considering this, reducing the pre movement phase duration could increase the occupant's opportunity to save him/herself.
- II. The movement phase is when the individual or group decide to move away from the environment that exposes them to danger.
- III. Completed evacuation: When the emergency evacuation process is successfully completed, i.e. the individual or group can leave the environment that exposed them to the risk and reach a safe place.

One of the biggest emergency evacuation reports occurred on September 11<sup>th</sup>, 2001, in the city of New York, when the the towers of the World Trade Center building collapsed. In this situation, a database emerged from reports of survivors, with the following information: The attitude taken by the survivors at the beginning, progress and end of the evacuation process, checking what were their actions, decisions, feelings and difficulties faced. It was also checked the time of action between the pre-movement and the end of the evacuation process. It is known that the fire in the buildings of the World Trade Center was not due to its structures, but rather from the aircraft friction. Although it was not a typical fire, this event is important to understand the occupants' behaviour during a fire emergency evacuation, allowing a better understanding of the complexity of the evacuation process in critical situations[13,14].

In the interviews of 275 survivors there were interesting answers, especially regarding the behaviour of individuals in the pre movement phase. The most prominent answers were: the collection of personal belongings; expect the verbal instruction of any individual; continue the routine work (because they believed that this was an emergency evacuation exercise); or were prevented by some obstacles. But the most notable response was that 45% of individuals had the initial attitude to evacuate, but were prevented from doing this as they were surrounded by smoke or flames[11].

Facing the fire, the faster the individuals perceived the situation as dangerous and moved to safety, the greater the chance they had of saving themselves and others involved in the event. The act of evacuating is nonetheless not only associated to the fact of finding the nearest emergency exit, but it is also to the concepts and personal aspects of individuals when confronted with the situation[6, 9,15] .

## 2.2. Models evacuation drills in fire

Emergency and critical situations are becoming increasingly common because the cases of environmental disasters (e.g., tsunamis, earthquakes, forest fire), terrorist attacks, buildings with structural damage (due to deterioration or by negligence in following the rules of structures). In contrast, the study of emergencies is growing exponentially, mainly focusing on critical and unexpected events. Individuals when exposed to such situations, respond with a high level of stress and concern, both for his/her life and survival, and by his/her family and colleagues. It is known however, that many individuals undergo training in their work environment in order to know how to act in emergency situations. The most common training is the emergency evacuation drills also called simulacrum.

This way, the various areas of knowledge (engineering, psychology, statistics), try to understand aspects of toxic gases derived from the smoke, the fire and the human behaviour before the fire, aiming to improve the training of individuals in order to survive and increase their safety[9,11,15].

Five types of methods can be highlighted in the training of emergency evacuation[13]:

- Hypothetical data: subjective analysis, in which videos are shown to the individuals or they are requested to imagine a scenario from which it is asked how they would react if they were in the imagined situation. This method can generate deviations related to the difference between behavioural intention and the real behaviour, but can be very useful to reconstruct a chain of events[13].
- Classical laboratory: real scenarios are used within a controlled environment of a laboratory, being acceptable as actual scenarios are transferred to a controlled environment of a laboratory. Individuals participating in the experiment are subject to stimulus that can cause stress and damage to some extent. It is important, in this type of method, to ensure the ethical aspects of research so that no participant is exposed to physical or psychological damage[13].
- Virtual Reality: simulated scenarios are used to represent emergency situations without exposing participants to real constraints. This method overcomes ethical problems that often arise in the classical laboratory studies. Thus, the participants may be exposed to an emergency (e.g., fire) with a greater control of the involved variables in order to gather important response, such as the participants' behaviour and their physiological data[13].
- Field Study: Emergency scenarios are used in a natural environment, that is, outside the laboratory environment. The use of real environments implies a low control over the variables involved, and thus the individual's behaviour in a specific situation is analyzed through observation.
- Case Studies: descriptive, exploratory or explanatory of an event. In this method, individuals report what they experienced in a real emergency situation[13].

### 2.2.1. Simulacrum

The simulacrum also known as emergency exercises are taken as trainings aimed at analyzing and familiarizing the individual to possible critical events. Usually, the fire alarm sounds initiate the exercise. According to the Law 207- 1532/2008 used in Portugal, emergency evacuation drills in the establishments, industries, hotels, should be held either annually or every two months. This varies with the type of establishment, number of workers and the type of activity. The implementation of emergency exercises may or may not be previously informed by supervisors to employees. However, it is always necessary, in the workplace, to have a group of people who are able to lead and assist other individuals, such as in a real fire situation. Of course, this event cannot be real due to the fact that exposing people to a real fire is not ethically allowed. Another aspect of the simulacrum is that it starts after a fire alarm[5].

The simulacrum are exercises and their repetition make individuals begin to consider the alarms as an afterthought, because every time the alarm rings they imagine that it is another exercise or a false alarm. This response is common to the extent that the reports of the World Trade Center showed many occupants reported they did not start the evacuation immediately because they thought it was a false alarm[16].

Some reports are highlighted considering these emergency evacuation exercises. In a study from the Canadian government an evacuation exercise was done in 3 buildings simultaneously and people's behaviour during the evacuation of about 1000 occupants was analyzed through video cameras. Participants had not been warned about

the occurrence of the exercise and it was observed that the people took an average of 50 seconds to start the evacuation. Although these individuals have participated annually in trainings and know which procedures should be taken, they had interesting initial responses, such as: finishing current phone calls, saving the documents in computers, collecting their belongings, and still many had to be asked to move as quickly as possible. These reactions can be related to the fact that when individuals are faced with the real fire alarm they tend to think it is just another evacuation drill, so they continue their activities. What often happens is that people do not react as they should, which implies the clue validations from the pre movement phase fail and the individuals do not realize that there is indeed an actual real emergency situation[4].

In another study [3] in a subway station, it was found that when the alarm was activated, passengers did not begin to evacuate and continued their activities such as reading books, chatting or quietly waiting for the subway to arrive

### *2.3. Human behaviour and the perception of risk:*

The key factors in the evacuation are linked to the individuals' attitude and their decisions. Generally the primary actions taken against a flame or fire is to inform people about the event, dressing or take personal items, remain in the same place (shock), wait for help and leave the site. Also human behaviour can be defined as the combination of physiological and psychological components, and the environmental situations of the moment (fire, smoke, noise) [15].

Human reactions and responses are very important in critical and emergency situations, and the following can be highlighted:

#### *2.3.1. Panic*

Panic is an event that occurs in the human body both emotionally and physiologically, decreasing the capacity individuals have in organizing their thoughts and in elaborating a more complex rational response. In a fire situation, individuals tend to adopt a hysterical response, where people lose control of their actions. However, the panic in these situations, even when individuals see the fire and feel the smoke, refer to the attitude of shock, since they do not believe that something serious is actually happening, [16,17,18].

#### *2.3.2. Stress*

Stress can be assumed as a generally uncomfortable emotional experience and it is often perceived by the biochemical, physiological and behavioural changes in human beings [19]. In a study in aircraft accidents, authors verified stress had a degrading influence on decision making. Between the 50's and 60's of the 20th century, a database was created with numerous aircraft accidents, concluding that a key factor was stress. After a decision-making model and hypotheses in situations that generate stress, found that the body has a tendency to opt for irrelevant information in the situation, that is, an attitude or thought that has no connection with the right attitude to take, influence the working memory and thus decreasing performance [20].

#### *2.3.3. Risk perception*

The first actions when facing a stimulus, such as a fire, is to understand, recognize and think. Before the individual take action it is a necessary for the individual to go through these three factors, this is known as risk perception. The perception is associated with an interpretation of the sensations generated by the experience and expectations of the individual [9, 14, 21]. The perception of risk is defined as something associative and emotional, which could cause two distinct situations: the first is the high perceived risk, which leads the individual to have a protective response (evacuation or search for a safer place) and the second is the low perception of risk, which implies a non protecting and ignoring the cues response[11]. Then, this is the mediator in the relationship of the predictor variable and protective action. Factors that may increase one's perception of danger are the reactions of other occupants (e.g., shouting). However, the perception can also be reduced when individuals are exposed to toxic fumes of smoke, as well as past experience with fire or training fire, which means that individuals who have had knowledge about the escape routes are likely to reduce the interpretation of the risk factor. All these events generate a series of signals that conflict in a pressure environment where individuals tend to be more prone to work with the

crisis from situations previously experienced. Three conditions are associated with increased risk perception: the sense of urgency, the presence of a loved one in the same environment and when the individual finds the situation as a real fire[11].

#### 2.4. Virtual Reality and the Transfer:

Virtual reality is defined as a real or simulated environment, in which the individual experiences the feeling of being present and not being limited only to environments generated on the computer, but in laboratories are also considered as virtual environment [14]. This tool has evolved over time, aiming to exceed any disadvantage presented in studies or in their use, and is currently used as training for individuals, such as pilots and doctors. Then, VR can be considered an important way to train individuals, because it overcomes the disadvantages that may affect real exercises, mainly considering risky situations [1].

Virtual reality has the ability to provide safe environments, low cost, and can be repeated several times, providing the learning of appropriate evacuation and rescue procedures [13, 22]. Virtual reality has been used to verify human behaviour against fire, as evacuations in buildings, the behaviour of occupants in tunnels and other training directed to security [23]. Concerning its usage, its strengths come from the relationship of the individual behaviour and front to fire.

As for the transfer, this is closely linked, absorbed and associated with learning and the ability of individuals who are exposed to practice. But it depends on the individual front the new technology capacity, either through repeated tasks, similar tasks or different conditions, so it may be that factors such as education level, age and even the technical knowledge, influence the interaction and absorption of knowledge [6, 24].

For the transfer to be positive, should contain an appropriate balance between knowledge, skill and attitude (KSAs) of individuals, front their real activities. But can occur, that training does not provide an impact, because what is being exposed to the individual does not have much to do with the activity of the actual work, and this, of not training absorption is referred to as negative transfer. Thus the more similar are the narrative and virtual scenarios, the real task of the employee, the more it is possible to obtain knowledge. Other aspects of the transfer are known as vertical and horizontal, respectively, in the first is found the individual's ability in front of the circumstances used in virtual reality, and the second is intended that the participant is able to apply what they have experienced in Virtual reality in many situations. Finally the individual has awareness and the effort to find the relationship between the desktop and the virtual [14, 25].

### 3. Discussion

The situations of fire and emergency are associated with many factors like fire, smoke and debris, physiological state (tachycardia, sweating, dizziness, tachypnea) and psychological aspects (panic, stress, denial situation). The beginning of the emergency evacuation study took place in the 20th century, which brought significant changes, such as the number of emergency exits, adequate signs types (still remains a research tool) and evacuation drills (standardized by laws), but human behaviour when facing fire has been still an issue and lacks investigation to be deeply investigated and as it is currently highlighted in several studies[2,15, 17, 26].

Questions remain regarding the use of evacuation drills, although they are important and necessary to familiarize individuals to the environment, so that when they are encountered with a real incident they will know what to do. Generally, participants are pre warned about the exercise, which will occur during working hours. When hearing the alarm, participants must follow the head of the command and perform their actions. However, with time and habituation exercises, many of the individuals fail to pay attention to the alarm, as to realise that something is wrong, but rather continue to practice their routine activities, believing that the sound of the alarm is always a routine emergency evacuation drill, thus not giving enough importance to the alarm.

This can actually compromise the survival of the individual, since the quicker the approach taken to evacuate, the greater the possibility of survival.

Of course that simulacrum train a specific situation evacuation and do not study other various forms and critical events that may occur outside of what is expected as normal. However, it is not what has been seen in the use of virtual reality for training, providing the transfer of knowledge to those who practice it. And this has been already



proved by using this tool, since it has been used in academic surgeons (physicians) and trainings of aircraft pilots [2, 17, 26]. As virtual reality has the ability to model the virtual environments and narratives it provides a more efficient and cost-effective way to enhance and secure the lives of all involved, and each again proven as a new form of training.

Virtual reality has been used by different areas of knowledge however it has increasingly stood out as an effective methodology in the area of emergencies and, more specifically, fire and evacuation. In emergency evacuation situations, the use of Virtual Reality has been in studies that focus mainly on situations of smoke and fire, the answers and the time and some behavioural aspects of human being. But all these situations are often used separately. And it is known that, in an emergency situation there are several interrelated factors, especially in situations not previously explored.

Having as exploring the usual situations already studied and several other within the virtual scenario and can highlight situations, not yet reported in the Virtual Reality in the emergency evacuation process as outputs that should be commonly used that are locked and also other people which has a reduced mobility as handles this situation, the unexpected arrival of a family member to the site at the time of the incident (emotional). Other various situations may be elected, but always focusing on events that may occur and so people are able to solve them. These situations and events can be studied (via individual's body by sensors, features and gestures of the participants, performance time) after being studied underwent analysis which will produce effective responses regarding the use or not of Virtual Reality in the specific training of emergency evacuation in case of fire, for the immersive environment is, it is known that the use of eye-tracker is a useful tool in immersive component [7].

There are numerous situations that can be studied in virtual reality, because this tool has the ability to change the scenarios, from scenarios and or situations that do not have adequate responses, and the essential, not causing harm to individuals' life and health.

#### 4. Conclusion

We conclude from the reports cited that when individuals are in a real fire situation, they have the tendency to either continue their normal activities, to deny that something wrong is happening, or even believe that the alarm is part of an exercise when it is not. Thus, virtual reality, can be a valuable tool, as the training can be more effective, with a lower cost and can intervene in the various aspects and features of the evacuation process as a whole. The use of this tool may produce a better response to individuals who are exposed to such situations. In addition, VR reduces cost and can increase the safety of individuals. Therefore, there is a need to develop and validate such tools.

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